Int J Life Cycle Assess (2014) 19:1632–1642
DOI 10.1007/s11367-012-0427-6

NON-TOXIC IMPACT CATEGORIES ASSOCIATED WITH EMISSIONS TO AIR, WATER, SOIL

Determination of regional acidification factors for Argentina

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Received: 26 April 2010 / Accepted: 1 April 2012 / Published online: 20 April 2012

Abstract
Purpose In the last decade, the use of life cycle assessment (LCA) as a tool for selection between different technologies or products fulfilling the same function has spread rapidly in Latin American countries. However, this accelerated growth in the use of LCA has not always been supported with progress in construction of local inventories or the development of impact assessment methods that consider local and regional characteristics of the sites where technologies, products, and activities or services are being produced or developed. The aim of this study is to propose a local methodology to estimate regional factors for the terrestrial acidification impact category in Argentina based on the critical load exceedance in sensitive areas.
Material and methods Acidification factors for ecological regions in Argentina were calculated following a procedure that compares acidic deposition with critical loads, using a linear function to represent the damage, when the deposition is above the soil buffering capacity. The acidic deposition in the study area was estimated using the air transport model wind trajectory model, with emissions from the global inventory EDGAR. Detailed soil maps were used in order to include the acidification sensitivity of the receiving ecosystems. Also, an application case of the calculated factors is presented in order discuss the relevance of the regional factors implementation in local studies.
Results and discussion Deposition fluxes were estimated for different ecoregions in Argentina. The regional factors calculated differ from site-generic factors used commonly to estimate potential impacts, demonstrating that their use in local studies could lead to erroneous outcomes. This was more evident in the application case, where the potential impact calculated was very different, depending on the impact factor used.
Conclusions and recommendations The model presented in this study allows the assessment of the impact caused by deposition of acidifying substances emitted during the life cycle of a product or process, taking into account the local characteristics where the intervention occurs, and it is the first development of a regional model for acidification within the LCA context carried out in Argentina. The obtained results highlight the importance of developing regional characterization factors for local or regional impacts referred to a definite region.

Keywords Acidification · Argentina · Life cycle assessment · Life cycle impact assessment · Regional impacts

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1 Introduction

ISO 14040 defines life cycle assessment (LCA) as "the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (ISO 1997). It is a tool that provides environmental information about potential impacts caused by emissions or resource consumption somewhere from raw material extraction to the final disposal. LCA has four phases: goal and scope definition, inventory analysis

(LCI), impact assessment (LCIA), and, the last one, interpretation. LCI quantifies environmental interventions (emissions, resource extractions, and land use) of a product system under study. LCIA translates the environmental intervention into potential impacts.The impact categories, indicators for those categories, and impact models to quantify the contributions of different environmental interventions to the potential impacts are then selected. Afterward, the information from the LCI is classified into impact categories, and then it is characterized by characterization factors, which transform inventory inputs into comparable impact indicators located at any distance between LCI results and the category endpoints (Seppälä 2003).

Historically, LCIA methodologies have not paid attention to the spatial aspects or the site where environmental intervention (e.g., emission and deposition) takes place (Potting et al. 1998a). In the last decade, the use of LCA as a tool for selection between different technologies or products fulfilling the same function has spread rapidly in Latin American countries. Several institutions promote diverse actions to incorporate life cycle thinking in companies, governmental agencies and academia. However, this accelerated growth in the use of LCA has not always been supported with progress in construction of local inventories or the development of impact assessment methods that consider local and regional characteristics of the sites where these technologies, products, and activities or services are being produced or developed. Moreover, specific computer programs for LCA are not adapted for their application in Latin American regions, which have usually different development contexts and limitations, than countries from Europe, Asia, and even Africa. Furthermore, most LCA studies carried out in Latin America use foreign inventories, and what is an even more questionable practice, employ foreign characterization factors or site-generic factors to characterize regional impacts (e.g., acidification). This may give erroneous outcomes that could then lead to make wrong decisions.

In the last years, characterization models have incorporated site-dependent conditions for nonglobal impact categories. They take into account the place where an emission is released, the subsequent atmospheric transport and the sensitivity of the receiving ecosystems. Site-dependent characterization factors are available for Europe and North America; however, there are not regional factors for Argentina and other Latin American countries so far.

Since 2004, a set of studies have been carried out in order to calculate site-dependent factors for regional impact categories (Civit et al. 2005, 2006; Arena and Civit 2006, 2007a, b, 2008; Civit and Arena 2006). The aim of this study is to propose a local methodology to estimate regional factors for the terrestrial acidification impact category in Argentina based on the critical load exceedance in sensitive areas. Furthermore, a practical case demonstrates how the inclusion of site-generic characterization factors in LCAstudies would lead to an erroneous outcome.

The results of the present study also give some new insights into the regionalization of characterization factors in Latin-American countries.

1.1 A brief overview of environmental conditions in Argentina

Argentina is situated on the south extreme of South America. It is the second biggest country in the region after Brazil with an extension of 3,761,274 km² (continent and islands) and has a wide diversity of ecosystems, topography, weather, and bioclimatic regions. In the northeast of the country, there are extreme humid conditions, while severe desert conditions are found in the midwest; plain terrains are typical in the “Pampa húmeda”, and peaks over 6000 m above sea level are characteristics in the Andes Mountains. Conversely, closed forests are common in the mid-north of the country, and enormous plateau of shrubs depicts the southern Patagonia. Since not all ecosystems react in the same extent against the same environmental intervention, obviously, these variations may produce different impacts on the environment. This implies that a single acidification factor for the whole extension of Argentina is not sufficient.

1.2 Acidification impact category

Acidification is one of the most frequently used impact category in LCA studies. Several substances may cause acidification of soils, water bodies, and ecosystems, but the three more relevant are sulfur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3). The acidification mechanism consists in a decrease in pH and an increase in acidity of water bodies or soils by the release of hydrogen cations [H^+]. Acidic deposition alters soil through depletion of labile pools of nutrient cations (i.e., calcium, magnesium), accumulation of sulfur and nitrogen, and the mobilization of elevated concentrations of inorganic monomeric aluminum to soil solutions in acid-sensitive areas.

Until recently, the acidification factors in LCIA methods considered only the substance’s acidifying ability to release [H+] (Heijungs et al. 1992), but in the last few years, acidification models started to include also spatial differentiation leading to current site-dependent acidification models.

Many authors meanwhile have dealt with the calculation of site-dependent acidification factors in different sites of the globe (Potting et al. 1998a, b; Bare et al. 2003; Huijbregts 2001; Guinée et al. 2001; Hettelingh et al. 2005; Krewitt et al. 2001; Seppälä et al. 2006; Posch et al. 2003; Goedkoop et al. 2003). These models have different definitions of the category indicator, partly depending on the

position in the casualty chain. But all of them consider the emission sources, background concentrations of acidifying substances, fate and exposure besides the substance intrinsic properties (Hetteligh et al. 2005). A detailed evaluation of category indicators and characterization models for acidification impact category can be found in Margni et al (2006).

2 Material and methods

2.1 Acidifying characterization impact model

Characterization in LCIA aims at estimating the potential contributions of different environmental interventions to several impact categories and, where possible, at aggregating the amounts of interventions (e.g., emissions along the complete Dijkshoorn a single number within each impact category (Seppälä 2003; Cónsoli et al. 1993). The emitted quantity of a given substance over the life cycle is multiplied by an equivalency factor that relates the emission with a reference substance, obtaining a category indicator. A category indicator is a quantifiable representation of an impact category, being the object of the characterization modeling (Seppälä 2003), that, according to ISO 14042, it "… involves the conversion of LCI results to common units and the aggregation of the results converted into the impact category." In the case of acidification, the equivalency factor is based on the amount of [H^+] that each acidifying substance can released (Potting et al. 1998b). When there is some spatial differentiation in non-global impact categories that discriminates among emission sources and their receiving environment, the equivalency factor is affected by a site factor (SF) that characterizes the geographical site where the emission takes place and the receiving deposition area (Potting and Hauschild 2006). In the latter situation, the equivalency factor is better called *characterization factor*. Usually, they are defined at the level of countries or regions within countries when regions have notorious differences between them like the case of Argentina.

The general scheme to calculate a category indicator according to ISO 14042 is:

$$\text{Category indicator} = \text{LCI result} \times \text{Characterization factor}$$

For this conversion, characterization factors are used, and, as result, a numerical indicator is obtained giving the environmental profile (Udo de Haes 1996).

The latter expression for terrestrial acidification can be represented by Eq. 1:

$$A_{(p)} = \sum_{i}^{n} E_{p,i} \times AF_{(\mathrm{reg}_n)} \quad (1)$$

where $A_{(p)}$ is the summed contribution from product p to acidification impact (kg SO_2 eq/functional unit), $E_{p,i}$ is the acidifying emission of substance i (SO_2, NO_x, NH_3) along the life cycle of product (p) and $AF_{(\mathrm{reg}\ n)}$ is the regional characterization factor for terrestrial acidification in region n. The latter is estimated by Eq. 2:

$$\mathrm{AF}_{(reg_n)} = \mathrm{SF}_{n,i} \times \mathrm{eq}_i \quad (2)$$

where $\mathrm{SF}_{n,i}$ is the site factor for substance i in region n, and eq_i is the equivalency factor for substance i representing the acidifying substance's ability to form hydrogen cations H^+_i.

2.1.1 Terrestrial acidification site factor

A $\mathrm{SF}_{n,i}$ characterizes whether a definite region is sensitive to terrestrial acidification. It is not recommended to calculate only one site factor corresponding to the whole country because of the wide differences existing among the regions within the country (Roig and Abraham 2003). In consequence, a definite site factor is calculated for each region n. Deposition may exceed the critical load of the receiving compartment and result in impact (Potting et al. 1998b). "Acidification will be avoided if deposition is maintained at a level that may be buffered by the soil" (Cinderby et al. 1998). Thus, $\mathrm{SF}_{n,i}$ is calculated by comparing the soil critical loads with the acidifying deposition coming from the usual emission sources in the regions. In that sense, the proposed model takes into account the difference between the deposition and the critical load that the receiving soil can tolerate without suffering acidification impact (Eq. 3).

$$\mathrm{SF}_{n,i} = \frac{D_{n,i} - \mathrm{CL}_n}{\mathrm{CL}_n} \quad (3)$$

where $\mathrm{SF}_{n,i}$ is dimensionless, $D_{n,i}$ is the deposition of substance i in the ecoregion n (mEq H^+/m^2 year) and CL_n is the critical load in the ecoregion n (mEq H^+/m^2 year).

Soils can receive a certain amount of acidic substances without suffering any harmful effect, depending on their chemical and physical properties. That limit is called critical load (CL) and it is the quantitative amount of acidic deposition which represents the threshold to damage (Nilsson and Grennfeld 1988), which depends on the soil resistance to changes in pH, i.e., its buffering capacity. The soil buffering capacity in this model is based on two parameters: cation exchange capacity (CEC) and base saturation (BS). The higher the CEC, the more resistant soils are to changes in pH. Base saturation is also related to soil pH and represents the availability of cations (such as calcium or magnesium) in percentage. BS and CEC together provide a ranking of soil buffering ability for five soil sensitivity classes (from 1 to 5), in which 1 is the most sensitive (Cinderby et al. 1998). Each sensitivity class is related to a

critical load value expressed in miliequivalents of H^+ per area unit and time unit[1] (meq H^+/m^2 year; Table 1).

In the areas where (Eq. 3) outcomes are 0, the critical load is not exceeded, and acidification will not occur. Therefore, the regional factors for these cases will be considered null. If CLs are exceeded, regional factors will be equal to that exceedance and so the acidification impact will be a linear function of the SF (Fig. 1).

Table 1 Sensitivity classes. Source: Cinderby et al. 1998

Sensitivity classes	Critical load (mEq H^+/m^2 year)
Class 1 (most sensitive)	25
Class 2	50
Class 3	100
Class 4	200
Class 5 (nonsensitive)	>200

2.2 Emission inventory

Acidifying substances are released to the atmosphere from different sources. These sources can be natural like volcanoes or anthropogenic like fuel combustion, livestock, and fertilization. After an acidifying substance is released, it disperses into the atmosphere and travels some distance before falling over soil, water, or biota. Deposition is the most important process in removing pollutants from the atmosphere. It can be dry or wet, depending on the transport mechanism to reach the receiving surface. Deposition may occur near the emission source or at several hundred kilometers from it, depending on atmospheric, meteorological, and topographical conditions. To calculate acidic deposition, an atmospheric transport model is needed. Such model allows incorporating regional data concerning emissions to air, transport trajectories, chemical reactions in atmosphere, and deposition velocities. The existing acidifying emissions in the region are computed to establish a reference scenario of concentration in the atmosphere and the further deposition over soil compartment.

The first step to evaluate the contribution of natural sources and human activities in acidic deposition is the properly estimation of the emissions of acidifying gases in the area under study. Emissions distribution in time and place of any individual chemical compound is not actually available in emission inventories compiled locally at national level in Argentina. Time- and space-resolved local emissions inventories are only available for major cities in the country (see Allende et al. 2010; Puliafito et al. 2011).

To overcome this problem, the new version of the Emission Database for Global Atmospheric Research (EDGAR v4.1) is used. This global emission inventory (Janssens-Maenhout et al. 2010) provides independent estimates of the global anthropogenic emissions and emission trends of acidifying substances (NO_x, NH_3, SO_2) for the period 1970–2005. All emissions are annually detailed at country level and also in grids of 0.1×0.1 degrees of resolution (about 10 km) for all modeled compounds. The inventory was developed combining activity data (from publicly available international statistics and, to the extent possible, emission factors as recommended by the EMEP/EEA air pollutant emission inventory guidebook. The gridded emissions were used directly as input for the WTM model to estimate acidic deposition in the whole country.

2.2.1 Acidifying emissions in Argentina

The emissions of acidifying compounds to air in Argentina, expressed as acidifying equivalents consists mainly of NH_3 (75.7 %), NO_x (18.4 %), and SO_2 (5.8 %). Manure in pastures, direct soil, road transportation, and agricultural waste-burning emissions contribute about 80 % to national total emissions. The emissions from soil and manure in pastures are mainly NH_3, while in road transportation, NO_x dominates. Combustion processes in electricity production resulted in the major contribution to SO_2 emissions (2.7 % of the total equivalents) and a great percentage of NO_x emissions (7.4 % of the total equivalents).

The total emission of acidifying substances is 10 % greater than in 1990. Although the emissions of SO_2 have strongly decreased, the level of NH_3 and NO_x emissions is increased in a 24 % and 1 %, respectively (Figs. 2 and 3).

2.3 Acidic deposition modeling

The acidic deposition from all sources in the study area is estimated using the air transport model wind trajectory model (WTM; Krewitt and Trunkenmüller 1995; Trukenmüller and Friedrich 1995; Trukenmüller 1998) included in the EcoSense System. The WTM model is a user-configurable trajectory model based on the windrose approach of the Harwell Trajectory Model developed at the Harwell Laboratory, UK. The model is a receptor-orientated Lagrangian plume model employing an air parcel with a constant mixing height of 800 m moving with a representative wind speed. The results are obtained at each receptor point by considering the arrival of 24 trajectories weighted by the frequency of the wind in each 15 ° sector. The trajectory paths are assumed to be along straight lines and are started at 96 h from the receptor point.

[1] As a consequence of not having enough information to consider a critical load function to integrate acidification coming from sulfur and nitrogen, all the acidifying emissions are converted into mEq H^+ first. Then, deposition values in mEq H^+ are compared to critical loads, and finally the category indicator is calculated.

Fig. 1 Behavior of the site factors vs. critical load exceedance

The software was successfully implemented in previous studies in Argentina to estimate the concentration and deposition of acid species on a regionwide scale (Allende et al. 2011) using the Windrose Model Interpreter (WMI) model (Trunkenmuller 1998).

For the deposition calculations, gridded receptors with a 50 km resolution were used including the whole Argentinean territory (from 56°S to 22°S and 74°W to 54°W), covering a total area of 2100×3500 km^2. Meteorological data (wind speed, wind direction, and precipitation) are included in the model, adapting measurements from 75 meteorological stations of the National Weather Service to the same regional grid created to assess air transport modeling.

The WTM model results have been previously validated for Argentina (see Allende et al. 2011 for more details) comparing the model outputs with those generated by a more complex chemical transport model, the Weather Research and Forecasting model with Chemistry (WRF/Chem; Grell et al. 2005). Similar deposition patterns were obtained with both tools, configured in the same manner, despite their different complexities and formulations.

2.4 Soil, the receiving compartment

With the aim of calculating the site factors $SF_{n,i}$ for different regions in Argentina, this study considers the Bailey's classification (Bailey 1996, 1998) which describes ecosystem regions (or ecoregions) with high quality resolution compatible with Geographic Information Systems. The author subdivides the continents into ecoregions with three levels of detail: domains (macroecosystems), divisions and climate subtypes, provinces or sites (microecosystems; Bailey 2002; Núñez et al. 2010). For this study the division classification was used.

A weighted average is made to obtain one sensitivity class for each of the n ecoregions according to the percentage of surface with a particular soil type (Fig. 4). In order to

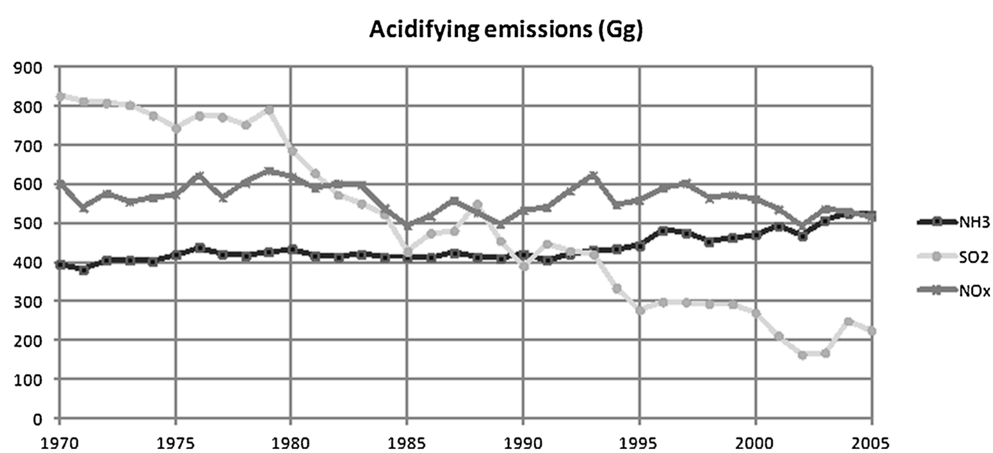

Fig. 2 Acidifying emissions in Argentina

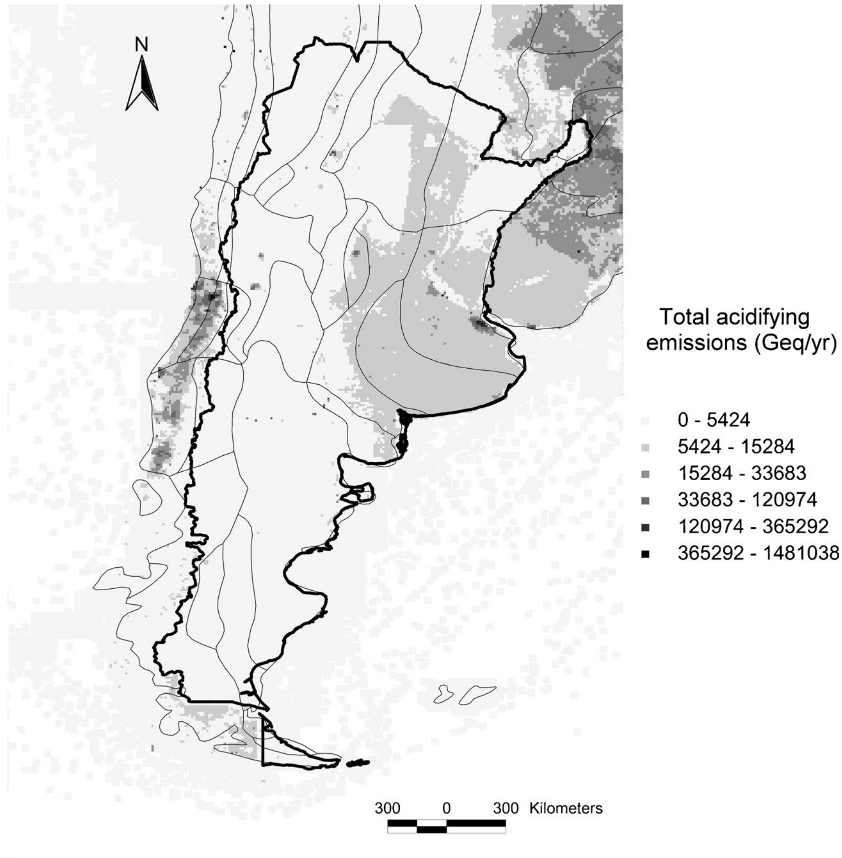

Fig. 3 Total acidifying emissions released within the Argentinean territory

include detailed soils information, we used the most recent Soil Map of Argentina from the Soil and Terrain Database for Latin America, version 2.0 (Dijkshoorn et al. 2005; FAO 2003). This reference map has a scale of 1:500.000 in the region under study and it was made according to the Soil Taxonomy 1975. A large portion of the territory present soils with sensitivity class 5 (insensitive), but the differences between the ecoregions within the country are remarkable: there are few definite ecoregions with some degree of sensitivity, possibly associated with soils with a high organic matter content, low pH and leafy forests on them.

A global analysis of the geographic distribution of potential risks of acidification was presented in Bouwman et al. (2002). Here, global maps of critical loads based on soils

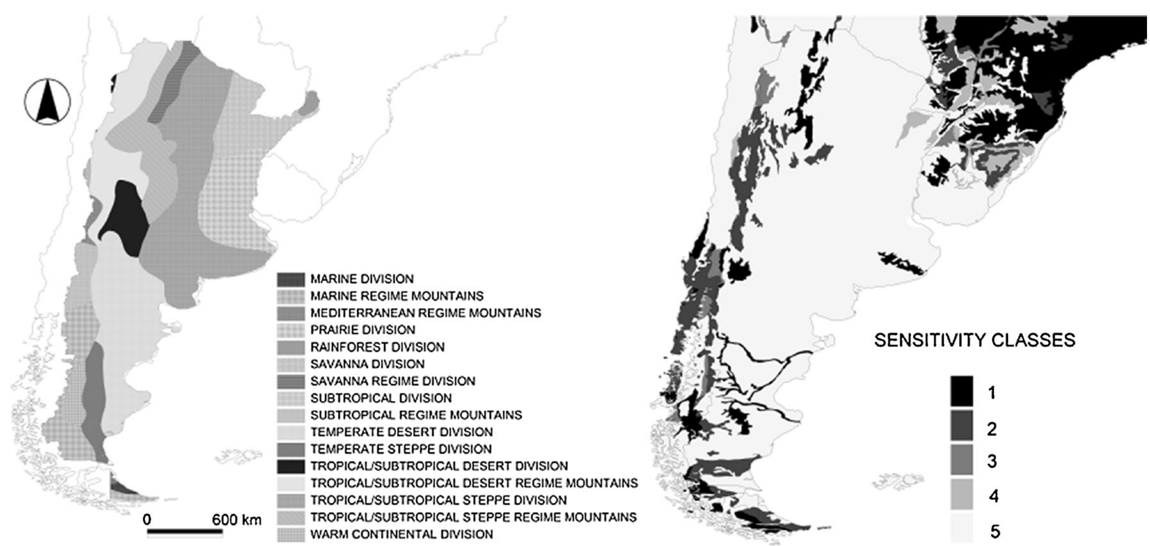

Fig. 4 Soils sensitivity to suffer acidification of ecoregions in Argentina according to Bailey 1998; Dijkshoorn et al. 2005, and Cinderby et al. 1998

and ecosystems characteristics were made using grid cells of 0.5–1 ° latitude and 0.5–1 ° longitude, without mentioning the results per ecoregion in Argentina However, the authors stated that the region nearby Río de la Plata is highly sensitive to suffer acidification, which is in discrepancy with the results found for the same region according to the sensitivity map of Argentina presented in this paper. Moreover, in the north eastern side of the country, the rainforest division limiting with Brazil has some degree of sensitivity which is not reflected in the results of (Bouwman et al. 2002). On the other hand, our results are consistent with those found in Bouwman et al. (2002) for the western side and the southern portion of the country.

The following sections show the results obtained for Argentina and the application of the model to a particular study case.

3 Results and discussion

Average deposition fluxes for the considered study area are given in Fig. 5. A large range of values can be seen, depending on the type of the source types and the environment where pollutants are deposited. Deposition rates for Argentina seem to be reasonable for a not a highly industrialized country. As seen in Fig. 6, acidic gases have the ability to travel long distances and pollutant concentrations and depositions decrease almost radially with distance from the emission sources. The greater amount of acidifying substances deposition occurs near the urban centers. Although the model also predicts acidic deposition several kilometers away from the sources, over water, outside the country borders (acidic emissions from the Buenos Aires urban center occurs in La Plata river and in Uruguay), and in different ecoregions from the ones emitting.

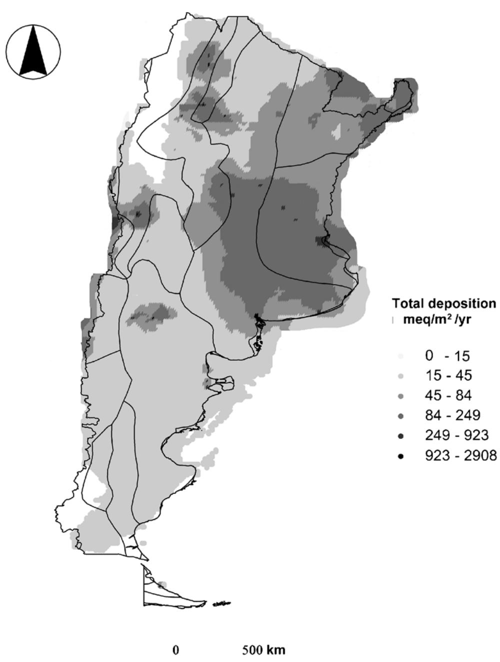

Fig. 5 Deposition of acidifying substances in Argentina in mEq H^+/m^2 year

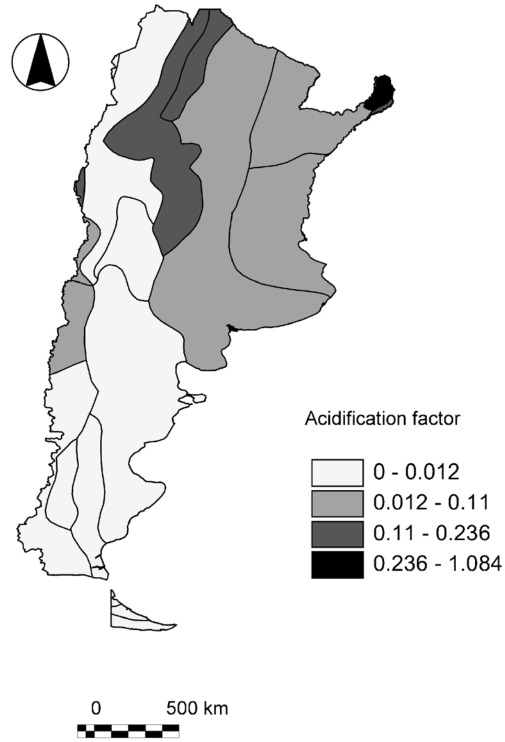

Fig. 6 Acidification factors for Argentina in kg SO_2 eq

An individual analysis for each ecoregion in Argentina, exceed the purpose of this work; however, the methodology proposed allows the precise estimation of where do the pollutants emitted by an ecoregion end up, and where do the pollutants in a given ecoregion come from. Source–receptor relationships used for control strategies (and for other purposes) can be easily extracted from the WTM model results. Although these source–receptor matrices are not presented, they are implicit in the model results.

The site factors calculated following the proposed procedure for each receiving ecoregion in Tables 2 and 3.

3.1 Application case

An application case is selected with the aim of demonstrating the importance of including regional acidification factors in Argentina.

LCA in the building sector is a suitable tool to select materials with low environmental impact and to optimize resources extraction by adopting new design solutions. Therefore, it is necessary to carry out a thorough analysis of all stages involved in the life cycle of buildings and their

Table 2 Site factors for the ecoregions of Argentina

Ecoregion (n)	$SF_{n,i}$		
Description	SO_2	NO_x	NH_3
Warm continental division	0.005	0.000	0.000
Subtropical division	0.000	0.001	0.000
Marine division	0.051	0.042	0.000
Prairie division	0.059	0.027	0.000
Tropical/subtropical steppe division	0.000	0.779	0.000
Tropical/subtropical desert division	0.000	0.061	0.000
Temperate steppe division	0.018	0.157	0.000
Temperate desert division	0.000	0.135	0.000
Savanna division	0.000	0.061	0.000
Rainforest division	0.001	0.000	0.000
Subtropical regime mountains	0.000	0.000	0.000
Marine regime mountains	0.000	0.000	0.000
Mediterranean regime mountains	0.003	0.006	0.000
Tropical/subtropical steppe regime mountains	0.005	0.052	0.000
Tropical/subtropical desert regime mountains	0.024	0.114	0.000
Savanna regime division	0.000	0.001	0.000

components in order to develop strategies to achieve environmental sustainability proposals.

The objective of this case of application is to show the differences in the results obtained when applying generic acidification factors and the differences obtained when using the regional acidification factors calculated with the model proposed in this study, which truly represent the impact resulting from the environmental intervention.

Table 3 Regional acidification factors for each ecoregion of Argentina

Ecoregion (n)	$AF_{n,i}$		
Description	kg $SO_{2\ eq}$		
	SO_2	NO_x	NH_3
Warm continental division	0.005	0.000	0.000
Subtropical division	0.000	0.001	0.000
Marine division	0.051	0.029	0.000
Prairie division	0.059	0.019	0.000
Tropical/subtropical steppe division	0.000	0.546	0.000
Tropical/subtropical desert division	0.000	0.043	0.000
Temperate steppe division	0.018	0.110	0.000
Temperate desert division	0.000	0.094	0.000
Savanna division	0.000	0.043	0.000
Rainforest division	0.001	0.000	0.000
Subtropical regime mountains	0.000	0.000	0.000
Marine regime mountains	0.000	0.000	0.000
Mediterranean regime mountains	0.003	0.005	0.000
Tropical/subtropical steppe regime mountains	0.005	0.037	0.000
Tropical/subtropical desert regime mountains	0.024	0.080	0.000
Savanna regime division	0.000	0.001	0.000

This case compares the use of sand–cement bricks instead of traditional (clay) bricks to build walls in homes. This type of alternative bricks need no cooking and is produced directly on the construction site, requiring no energy. They have instead cement in its composition, which involves a series of environmental consequences of the production process of cement clinker, a large consuming of heat and electricity process.

The functional unit used in this case is defined as "the environmental impact caused by the construction of the walls in a building, with 88 m² surface for housing, including their service areas along 50 years, considering the energy losses for heating during the winter during its life"(Mitchell and Arena 2001). It takes a house and four alternative wall construction: (a) two with traditional bricks, with and without insulation (wall 1 and wall 3, respectively); and (b) two with sand–cement bricks, with and without insulation (wall 2 and wall 4, respectively).

Each type of wall is evaluated using site-generic factors (Heijungs et al. 1992) and the regional characterization factors calculated for Argentina in this work.

The results show that when considering generic characterization factors, the wall 2, built with traditional bricks, is maybe more benign, because the alternative is to have the least impact on acidification in any site where the LCA is performed. However, when applying the calculated regional factors, the acidification impact varies in all cases: in the tropical/subtropical desert and subtropical ecoregion the use of generic factors underestimates the impact, and the opposite happens in the case of a clearly sensitive ecoregion like forest. In the latter, the use of site-generic factors overestimates the impact (Fig. 7).

Although a more complete analysis could be performed including other impact categories, and the final technology selection could be different, the application case has the purpose to highlight the differences obtained including the actual site conditions.

4 Conclusions and recommendations

The site factors in the proposed procedure are a measure of the receiving ecosystem sensitivity to acidic deposition or, in another way, a potential measure of a given region to suffer acidification.

In the proposed model three dimensions of analysis are considered:

1. The intrinsic properties of acidifying substances to release hydrogen.

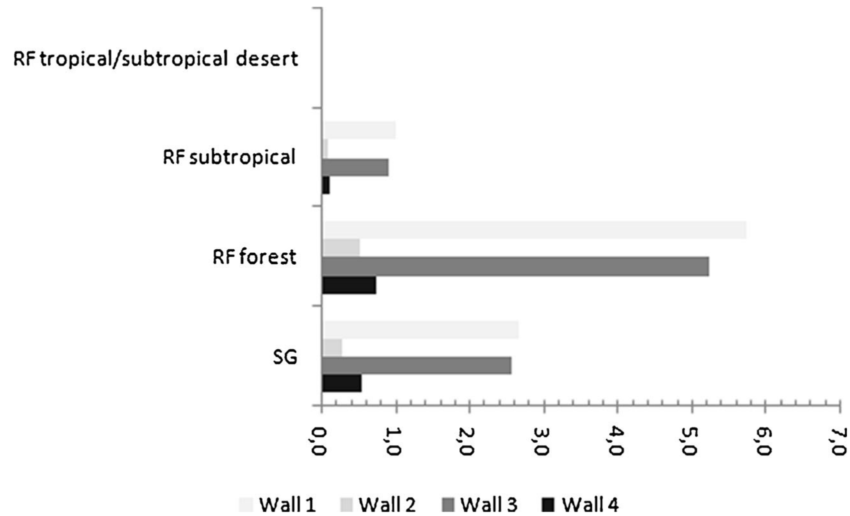

Fig. 7 Different results on Acidification impact category using site-generic factors (SG) and regional factors in three ecoregions of Argentina, expressed in kg SO_2 eq

2. The characteristics of the receiving targets, taking into account their sensitivity to acidic deposition.
3. The deposition of these substances over terrestrial ecosystems of the considered region.

In summary, the methodology to calculate regional acidification factors for the Argentine territory has an accounting of global acidifying emissions, the conversion of all the acidifying emissions into the same units, the use of a trajectory model to find deposition values for each ecosystem type, the comparison between the deposition and the critical loads in each ecosystem type and finally, the determination of the regional acidification factor. It must have in mind that the methodology developed and described in this paper matches the level of complexity of the difficult calculations with the quality of available data found for Argentina. That is why the regional acidification factors obtained represent a reasonable way of assessing the acidifying impact in Argentina.

The most significant result of the research carried out is the acidification model itself. This is the first development of a regional model of acidification within the LCA context carried out in Argentina. Its importance relies on allowing the assessment of the impact caused by deposition of acidifying substances emitted during the life cycle of a product or process, taking into account the characteristics of the place where the intervention occurs, which until now could not be done but with foreign equivalency factors. On the other hand, it becomes evident that acidification may be not a relevant impact to be considered in the LCA studies performed in several sites of Argentina due to the insensitivity of their soils while it could be excluded in sensitive areas like the northeast of the country. In a wider prospective, the results of the application case using the calculated factors for terrestrial acidification impact confirm that the use of foreign LCIA methods may lead to erroneous outcomes. The calculated factors, in some cases, widely differ from site-generic factors commonly used for calculating potential impacts and thus demonstrate that the use of those factors could lead to incorrect decisions. The obtained results show the importance of developing regional characterization factors for local or regional impacts referred to a definite region.

It is interesting to highlight that even when considering emissions scenarios with a moderate environmental policy for Argentina, emission levels of acidifying compounds and acidic deposition would increase considerably in some regions with high levels of industrialization and demographic density. A sensitivity analysis may be conducted as a simple means to evaluate how the regional acidification factors would reflect the changes in emissions.

Finally, the proposed procedure is a simplification of a complex reality, and a substantial effort has been made on the development of a model that encompasses the main issues related to the LCIA aims (objectives) as well as the regional reality regarding data and models availability. It provides a regional approach to calculate characterization factors particularly for Argentina, but it could be extended to Latin America, in general, avoiding the use of foreign factors in LCA studies. As reported in the latter issue, it is worthwhile to mention that a preliminary study was performed for Parana State in Brazil (Lazari et al. 2009) based on the initial stages of the impact model proposed in this paper obtaining satisfactory results

Further research is thereby needed in order to continue developing regional factors for other impact categories like terrestrial and aquatic eutrophication.

Acknowledgments The authors want to thank Dr. Enrique Puliafito for giving and processing the acidifying emissions data and for contributing with their knowledge about air quality issues and dispersion models; to Dr. Alfred Trukenmüller for his continuous guide on the adaptation of the WMI; to Miss. Laura Rojo and Miss. Andrea Oliva from the National Technological University who processed

information of WMI. Finally, the authors also thank the UNEP/SETAC Life Cycle Initiative for their support through the LCA Award activity 2008–2009 and the software providers Pre Consultants who sponsored the tools used.

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